Air Pollution and Control of Cargo Handling Equipments in Ports

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Abstract. In order to reduce and control air pollution caused by cargo handling equipments in ports, China's transportation authority has proposed the goal of accelerating the elimination of old high-emission cargo handling equipments. This paper studies and constructs a dynamic method based on the level of cargo handling equipments activity to estimate the emissions of atmospheric pollutants. The results show that in 2017, if the engines of cargo handling equipment are upgraded and comply with Chinese standard Tier III, the air pollution will be significantly reduced. We show the ranking of the emission of air pollution of different type of equipment in ports. The government will make a good decision on air pollution and control with our research results.

1 Introduction

In order to prevent and control atmospheric pollution, and improve the quality of the atmospheric environment, China is fully implementing air pollution prevention and control measures. The Department of Transportation has proposed measures to accelerate the elimination of old high-emission cargo handling equipment in ports. Diesel-powered cargo handling equipment in ports emits gases such as SO_2, NO_x, CO, HC, PM and so on during the operation process. Due to their large varieties and distributions, the calculation of pollutant emissions has become a difficult issue.

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Diesel-powered cargo handling equipment belongs to non-road mobile machinery, so it should implement pollutant discharge standards for non-road mobile machinery, namely "Limits and Measurement Methods for Diesel Exhaust Pollutants Used in Non-Road Moving Machinery" (China Tier III, IV) (GB20891- 2014) [1]. From April 1st, 2016, the standard stipulates that the manufacture, import, and sales of non-road mobile machinery equipped with Tier II diesel engines shall be stopped.

At present, the United States, Switzerland and other countries have developed official emission inventory of air pollution from non-road mobile [2, 3]. Some researchers in the European Union, the United States, and China have done research on emission inventory of air pollution from non-road mobile [4,5,6,7,8,9,10,11], Tan Hua studied on emission inventory of air pollution from cargo handling equipment in ports [12]. The study used fuel method to estimate air pollutions emissions and emissions sharing rates in different kinds of the port in Shanghai. The study has established magnitude for the total discharge volume of diesel-powered machine in ports. However, Tan Hua did not consider the impact of the activity level of the machine, engine power and engine type on the emission of air pollutants.

Based on the survey of the quantity and activity level of cargo handling equipment in ports, we develop a kind of dynamic method for estimating the emissions of air pollutions from cargo handling equipment and its engines. We use this method to calculate emissions for older cargo handling equipment that meets the "Limits and Measurement Methods for Diesel Exhaust Pollutants Used in Non-Road Moving Machinery" (China Tier I, II) (GB20891-2007) [13]. The estimation laid the foundation for the subsequent formulation of government policies in China.

2 Research object and scope

2.1 Research object

The research object in this article refers to diesel-powered cargo handling equipment whose engine type complies with china tier I or II, including forklifts, loaders, yard tractors, trailers, dump trucks, side handlers, top handlers, rubber tired gantry crane (RTG) and so on. Container terminal quay cranes are electric drive equipment, they are not the subject of research.

2.2 Research scope

The scope of research covers 21 provinces and cities with ports in China, including Guangdong, Shandong, Zhejiang, Jiangsu, Liaoning, Fujian, Guangxi, Hainan, Anhui, Yunnan, Guizhou, Jiangxi, Hubei, Sichuan povince, Heilongjiang and Hebei Province, in addition to Shanghai, Chongqing, and Tianjin City.

3 Research measure

3.1 Calculate measure

Based on the survey of the quantity and activity level of cargo handling equipment in ports, we develop a kind of dynamic method for estimating the emissions of air pollutions from cargo handling equipment and its engines, as shown in formula (1).

$$E = \sum (Q \times P \times H \times EF) \times 10^{-6} \quad (1)$$

E, pollutant emissions (t/a) , the types of pollutants include SO_2,NO_x,CO,CH,PM_{10} and $PM_{2.5}$
Q, equipment quantity
P, engine power (kW)
H, working hours in one year (hours)
EF, emission factors (g/kWh).

3.2 Parameter selection

Through the investigation we have obtained the following information including equipment name, equipment power, and date of manufacture, emission standards and fuel consumption in 2017. The example of equipment information is shown in Table 1.

Table 1. The example of equipment information

No.	Equipment name	Engine power(kW)	Date of manufacture	Emission standard (tier I or II)[a]	Fuel consumption (t/a)
1	Forklift	162	1998.06	tier I	2
2	Loader	163	2012.08	tire II	77
3	Yard tractors	189	2010.01	tier II	457.4
4	Dump Truck	221	2006.03	tier I	0.68
5	Tractor	196.25	2011.09	tier II	3.39
6	Side Handlers	158.8	1993.04	tier I	0.19
7	Top Handlers	250	2001.03	tier II	18.08
8	Top Handlers	404.25	1999.09.01	tier I	57.48
9	RTG	58.8	2012.12	tier II	0.8

3.2.1 Equipment quantity

Through statistics on the survey data, we obtained the number of different types of equipment equipped with Tier I and II diesel engines. The number of equipment engine (Tier I or II) is shown in Table 2. According to Table 2 , the total number of equipment is 7831 .The proportion of forklifts, loaders, yard tractors, dump trucks, trailers, side handlers, top handlers, rubber tired gantry cranes (RTG), and other equipments were 33.3%, 21.3%, 11.5%, 5.2%, 9.2%, 3.7%, 3%, and 9.6%, respectively.

Table 2. The number of equipment engine (Tier I or II)

Tier	Forklift	Loader	Yard tractor	Dump truck	Trailer	Side handler	Top handler	RTG[a]	Others
I	363	183	120	8	115	40	34	15	160
II	2246	1482	784	401	607	247	215	223	588
Total	2609	1665	904	409	722	287	249	238	748

3.2.2 Engine power

The power value is an important parameter for calculating the pollutant emission. We determine that the average power in a certain power range represents the power value parameter of formula 1. In order to obtain the average power, we first divide power ranges，then calculate the ratio of the equipment in different power ranges, and finally calculate the power average value. The power interval is divided according to Chinese standard of GB 20891-2007. We counted the number of equipment to be compared with the power range and calculate the ratio of the equipment in different power ranges.
The distribution of equipment in different power ranges is shown in Table 3.

According to Table 3, we can see that although distributed in the same power range, different types of equipment account for different proportions. For example, the power in less than 37 kW, the proportions from the largest to the smallest, there are forklifts, loader, yard tractor, trailer and trailer, and dump truck, top handler and RTG is zero. The same type of equipment also has different proportion in different power intervals. For example, the proportions of forklifts which power less than 37kW, [37,75)kW, [75,130)kW and [130,560)kW were 11.54%, 39.66%, 38.06% and 10.74%. The forklift power is relatively small, mainly distributed in less than 130 kW, other types of equipment power is relatively large, mainly distributed in [130, 560) kW.

Table 3. The distribution of equipment in different power ranges (%)

Power(kW)	Forklift	Loader	Yard tractor	Dump truck	Trailer	Side handler	Top handler	RTG	Others
<37	11.54	2.84	0.58	0	0.34	0	0	0	1.00
≥37& <75	39.66	10.07	30.92	0	7.16	0	0	4.29	16.03
≥75& <130	38.06	10.50	3.47	0.24	18.06	5.26	0	1.72	21.04
≥130&<560	10.74	76.59	65.03	98.76	74.45	94.74	100	93.99	61.94

By the ratio of the equipment and power value in different power ranges, we calculate the average power value in different power ranges of different type equipment. Average power value of equipment is shown in Table 4. According to Table 4, we can see that although distributed in the same power value range, the average power value of different types of equipment is different. For the equipment which power value less than 37kW and [37, 75) kW, their average power value shows little difference. For the equipment whose power value distributed in [75, 130) kW，side handler has the highest power, with an average power value of 123 kW. For the equipment whose power distributed in [130, 560) kW , dump truck has the highest power, with an average power value is 236 kW.

Table 4. Average power value of equipment (kW)

Power(kW)	Forklift	Loader	Yard tractor	Dump truck	Trailer	Side handler	Top handler	RTG	Others
<37	34	35	35	0	35	0	0	0	35
≥37& <75	50	58	55	0	55	0	0	73.5	55
≥75& <130	92	96	82	105	120	123	0	109	120
≥130&<560	180	172	200	236	196	172	232	158	172

3.2.3 Working hours

An important factor in estimating emissions is actual working hours of equipment. The working hours are related to the type of equipment and the busyness of port. At present, there are few statistical data on working hours of diesel-powered cargo handling equipment in ports. We determine the working hours is 770 one year, which originates from the “Guidelines for the Preparation of Atmospheric Pollutant Emission Inventory for Non-road Moving Sources” by the Ministry of Environmental Protection [14]. Working hours represent annual averages of equipment operation.

3.2.4 Emission factors

The emission factor is usually affected by the degree of equipment degradation. Wear of the engine components of the equipment ， or the use of emission control treatment equipment leads to a reduction in the efficiency of the equipment, further causing changes in the amount of equipment pollutant emissions. At present, there are few actual measurement data on cargo handling equipment's air pollutant emission factors. The emission factors of PM_{10}, $PM_{2.5}$, HC, NO_x, and CO refer to the Ministry of Environmental Protection's Guide to Non-Road Mobile Source Emission Inventory [14]. For the emission factor of SO_2, we uses the fuel balance method to calculate, assuming that all the sulfur elements in the fuel are converted to SO_2, and the common diesel used in the cargo handling equipment has sulfur content of 10 mg/kg [15]. The SO_2 emission factor is determined to be 20mg/kg. Diesel-powered cargo handling equipment emission factors are shown in Table 5.

Table 5. Emission factors(g/kWh)

Power(kW)	Tier	PM_{10}	$PM_{2.5}$	HC	NO_X	CO
<37	I	1.00	0.95	1.30	10.50	6.50
<37	II	0.95	0.90	1.30	7.50	6.50
<37	III	0.55	0.52	1.10	6.00	5.00
≥37& <75	I	0.85	0.81	1.30	9.20	6.50
≥37& <75	II	0.4	0.38	1.3	7	5
≥37& <75	III	0.35	0.32	1	3.5	4.5
≥75& <130	I	0.7	0.67	1.3	9.2	5
≥75& <130	II	0.3	0.29	1	6	5
≥75& <130	III	0.25	0.23	0.8	2.8	4.5
≥130&<560	I	0.54	0.51	1.30	9.20	5.00
≥130&<560	II	0.20	0.19	1.00	6.00	3.50
≥130&<560	III	0.18	0.16	0.80	2.80	3.00

4 Result and analysis

4.1 Cargo handling equipment's pollutant emissions

Based on the above calculations, the pollutant emissions of cargo handling eqiupment equied with engine Tier I and II in 2017 is shown in Table 6.

Table 6. The pollutant emissions of Tier I and II in 2017 (t/a)

Equipment name	PM_{10}	$PM_{2.5}$	HC	NO_X	CO	SO_2	Total
Forklift	78.43	74.56	147.53	1056.38	623.59	0.29	1980.77
Loader	185.12	176.22	547.65	3334.30	2235.94	3.52	6482.74
Yard tractor	95.19	90.62	285.55	1732.74	1157.77	0.22	3362.09
Dump truck	25.54	24.42	108.02	651.07	427.65	0.07	1236.77
Trailer	85.02	81.02	249.12	1523.59	1027.64	0.16	2966.54
Side handler	19.07	18.24	67.92	420.23	276.89	1.63	803.98
Top handler	10.96	10.40	46.30	286.32	164.80	1.93	520.71
RTG	18.05	17.08	63.58	355.43	266.27	0.4	720.81
Others	70.29	67.01	199.26	1211.29	825.94	2.26	2376.05
Total	587.66	559.56	1714.93	10571.35	7006.48	10.48	20450.47

According to Table 6, in 2017, the air emissions of cargo handling equipment equipped with Tier II diesel engines in ports were total 20450.47 ton. PM_{10}, $PM_{2.5}$, HC, NO_x, CO and SO_2 were 587.66t, 559.56t, 1714.93t, 10571.35 t, 7006.48 t, and10.48t, respectively, of which NO_x emissions were the largest, followed by CO, HC, PM_{10}, and $PM_{2.5}$, SO_2 emissions were minimum.
According to the type of equipment, the pollutant emissions is ranked from largest to smallest, the loader is the largest pollutants, followed by yard tractor, trailers, forklift, dump truck handler, RTG, top handler is the smallest pollutants. It shows that the emission of a certain type of equipment is positively correlated with the quantity of equipment and the power of the engine. The more the number of equipment distributed in the high power range, the greater the pollutant emissions. The loader engine has a maximum quantity of power distribution of [130,560)kW, and the total amount of equipment retained is the second, so the pollutant emissions is the largest.
In order to compare the value of emissions from equipment which engines upgraded to III, we assume that in formula except for the change of emission factor, other parameters are unchanged, and calculate the pollutant emissions, the result is shown in Table 7.

Table 7. The pollutant emissions of Tier III (t/a)

Equipment name	PM_{10}	$PM_{2.5}$	HC	NO_X	CO	SO_2	Total
Forklift	33.15	31.34	66.29	361.61	301.34	0.29	794.02
Loader	125.45	115.64	425.00	1695.38	1819.23	3.52	4184.22
Yard tractor	68.04	62.62	233.60	929.55	987.74	0.22	2281.77
Dump truck	21.65	19.50	85.91	280.85	371.77	0.07	779.75
Trailer	59.22	54.52	201.70	782.65	877.27	0.16	1975.52
Side handler	13.64	12.33	52.15	166.23	236.35	1.63	482.33
Top handler	8.01	7.12	35.59	124.55	133.44	1.93	310.63
RTG	10.38	9.71	33.49	138.23	157.24	0.4	349.46
Others	53.40	49.20	180.33	713.96	775.24	2.26	1774.39
Total	392.93	361.97	1314.07	5193.01	5659.63	10.48	12921.61

According to the Table 7, in 2017, the air emissions of cargo handling equipment equipped with tier III diesel engines in ports is total 12921.61 ton. PM_{10}, $PM_{2.5}$, HC, NO_x, CO, and SO_2 were 392.93t, 361.97t, 1314.07t, 5193.01 t, 5659.63 t, and 10.48t, respectively, of which CO emissions were the largest, followed by NO_x, HC, PM_{10}, and $PM_{2.5}$, SO_2 emissions were minimum. Sort different types of equipment according to their pollutant emissions from largest to smallest, the sorting result is the same as that of the engine in tier I and II.
We can find a total reduction of 7528.86 ton of emissions through upgrading the engine of the equipment, PM_{10}, $PM_{2.5}$, HC, NO_x, CO, and SO_2 were 194.73t, 197.59t, 400.86t, 5378.34 t, 1346.85 t, and 0t, respectively, of which NO_x emissions were the largest, followed by CO, HC, $PM_{2.5}$, and PM_{10}, SO_2 emissions were zero. According to the type of equipment, the pollutant emissions is ranked from largest to smallest, the loader is the largest pollutants, followed by forklift, trailers, dump truck, RTG, yard tractor, top handler is the smallest pollutants. Comparison of pollutant emission reduction before and after engine upgrade is shown in Table 8.

Therefore, the effect of less pollutant emissions is significant through upgrading the engine of the equipment, we recommend that the government can refer to the ranking of pollutant emissions when making decisions on the elimination of old high-emission equipment in the port.

Table 8. Emission Reduction Before and After Engine Upgrade (t/a)

Tier	Forklift	Loader	Yard tractor	Dump truck	Trailer	Side handler	Top handler	RTG	Others	Total
I and II	1980.77	6482.74	3362.09	1236.77	2966.54	803.98	520.71	720.81	2376.05	20450.46
III	1186.75	2298.52	1080.33	457.02	991.02	321.65	210.08	371.36	601.66	7518.39
Reduction	794.02	4184.22	2281.76	779.75	1975.52	482.33	310.63	349.45	1774.39	12932.07

4.2 Uncertainty

In this paper, the average working time of cargo handling equipment is 770 hours/year. The value derived from the "Guidelines for the Preparation of Air Pollutant Release Lists for Non-road Moving Sources" of the Ministry of Environmental Protection. The actual working time of cargo handling equipment varies according to type of equipment, in addition, the impact of the engine's useful life on pollutant emissions has not been taken into account. The value of the emission factor comes from the "Technical Guidelines for the Preparation of Atmospheric Pollutant Release Lists for Non-Road Mobile Sources" by the Ministry of Environmental Protection. This data is mainly based on bench tests of diesel engines. The research subjects are all cargo handling equipment of engines in Chinese tier I and II. The average life of survey equipment is 7 to 10 years, resulting in a relatively small calculation result.

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